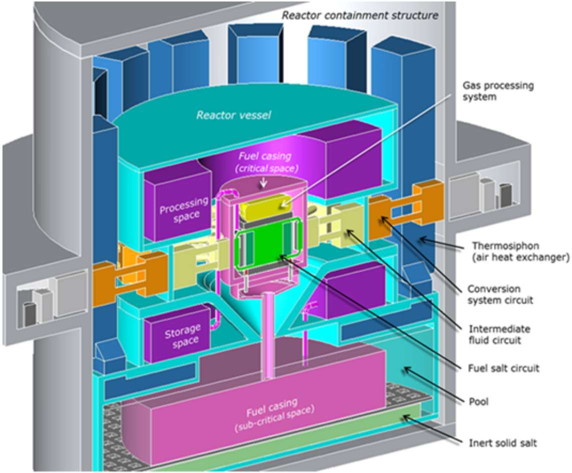
MODELLING OF THE DYNASTY EXPERIMENTAL FACILITY FOR NATURAL CIRCULATION UNDER DISTRIBUTED HEATING

Carolina Introini, Gabriele Benzoni, Antonio Cammi, Stefano Lorenzi

Technical Meeting on state-of-the-art Thermal Hydraulics of Fast Reactors, 26-30/09/22

Introduction

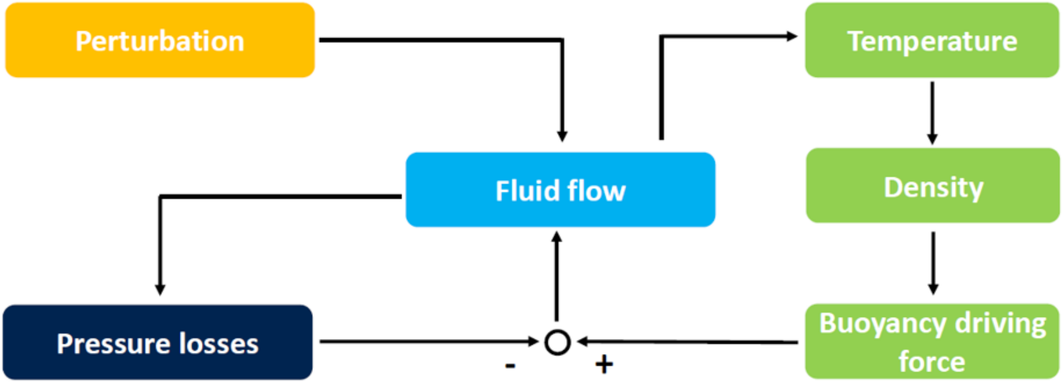


NATURAL CIRCULATION

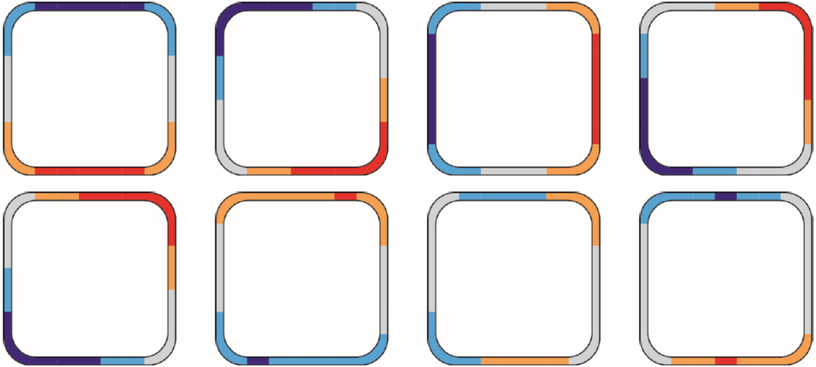
- **Passive Safety Systems**
- **Gen-IV ; Molten Salt Fast Reactor (DHRS with Internal Heat Generation)**

SAMOSAFER

Natural Circulation



Natural Circulation

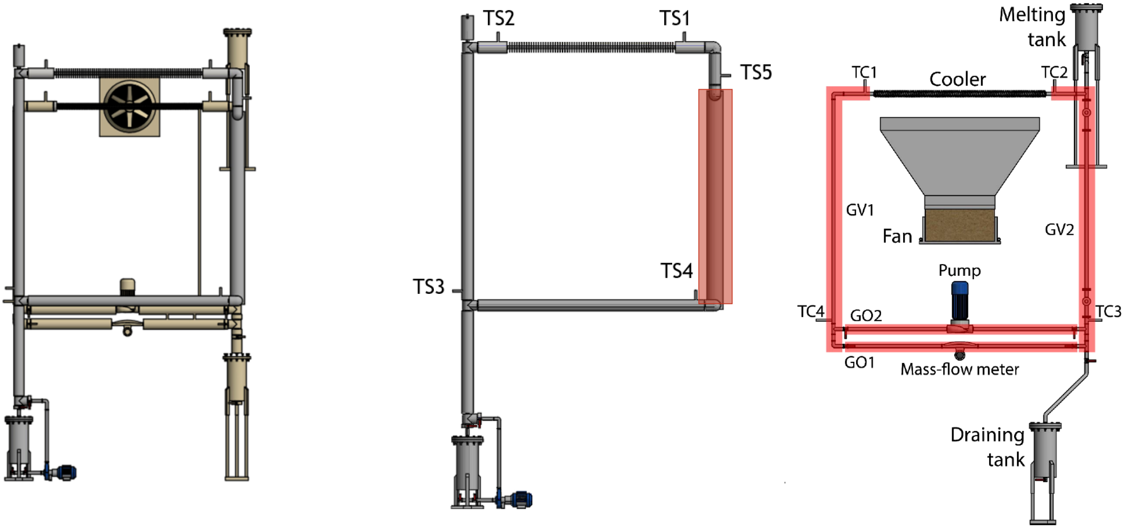


- Flow behaviour in loops is governed by density wave instabilities (Welander).
- Possible flow inversion and recirculation regions

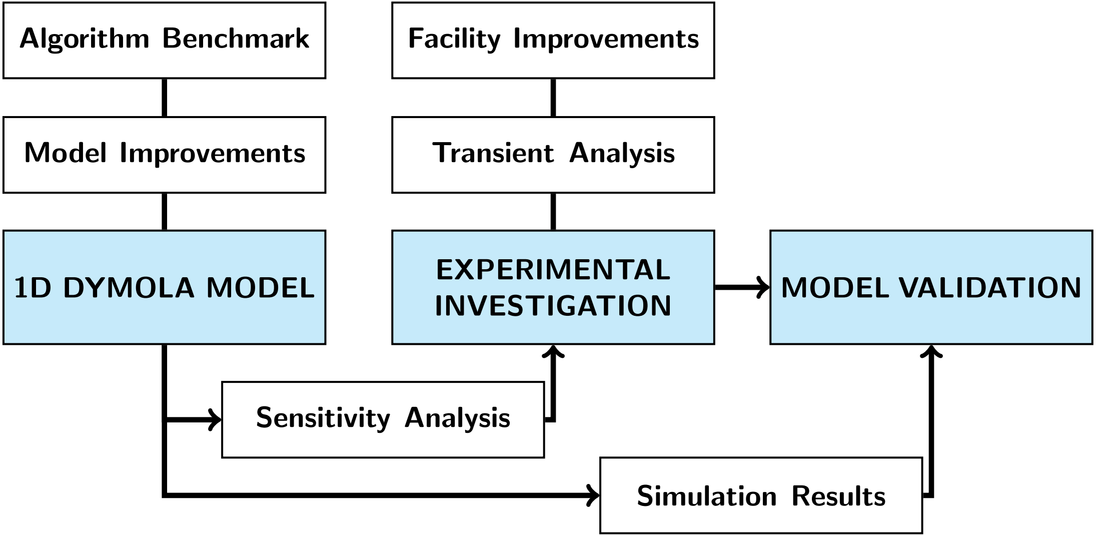
DYNASTY Configuration

- IHG simulated through DEHS
- No insulation
- Maximum heating power per leg (step)
- Working fluid: water
- Temperature working threshold: 95 °C
- Clockwise mass flow taken as positive

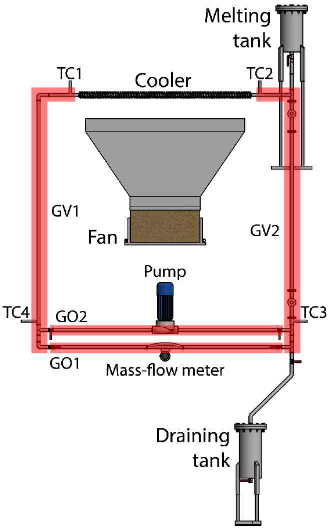
Coupled System



Outline

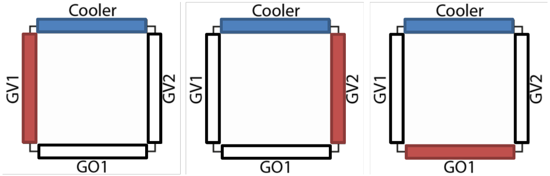

Algorithm Benchmark
Facility Improvements
Model Improvements
Transient Analysis
1D DYMOLA MODEL
EXPERIMENTAL INVESTIGATION
MODEL VALIDATION
Sensitivity Analysis
Simulation Results

DYNASTY Configuration

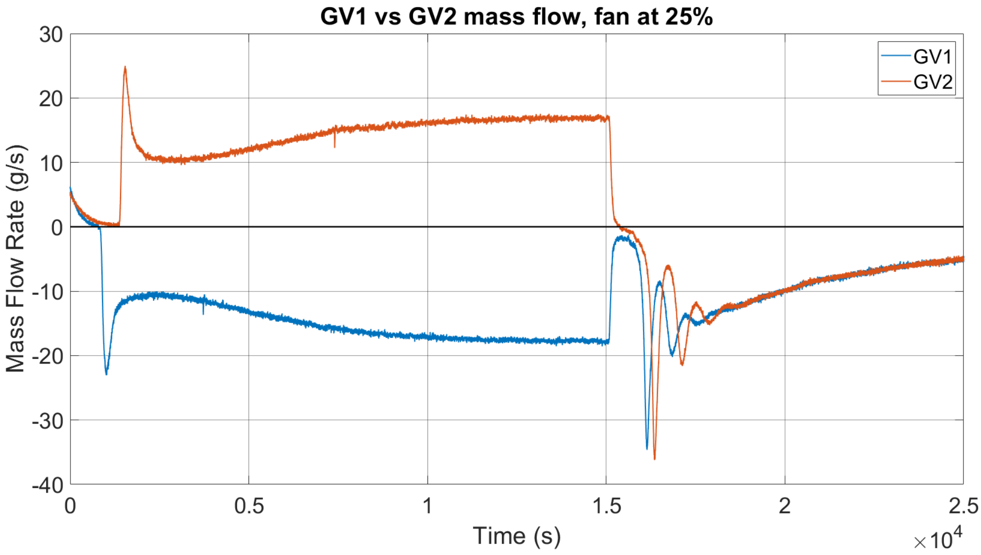


	VHHC GV1	VHHC GV2	HHHC GO1
	0%	0%	0%
	25%	25%	25%
	50%	50%	50%
	75%	75%	75%
Power	1800 W	1800 W	800 W

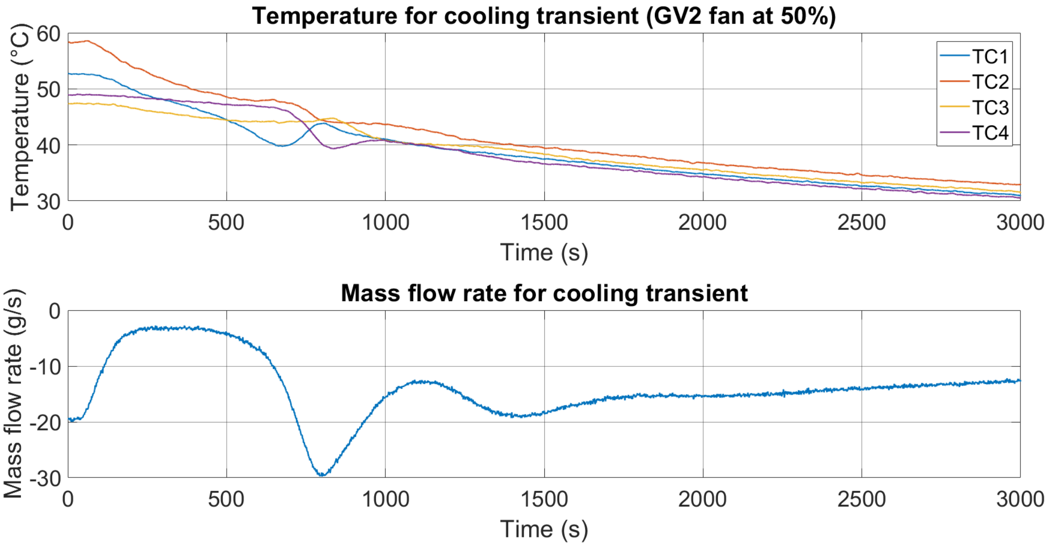
Table: Fan speed values



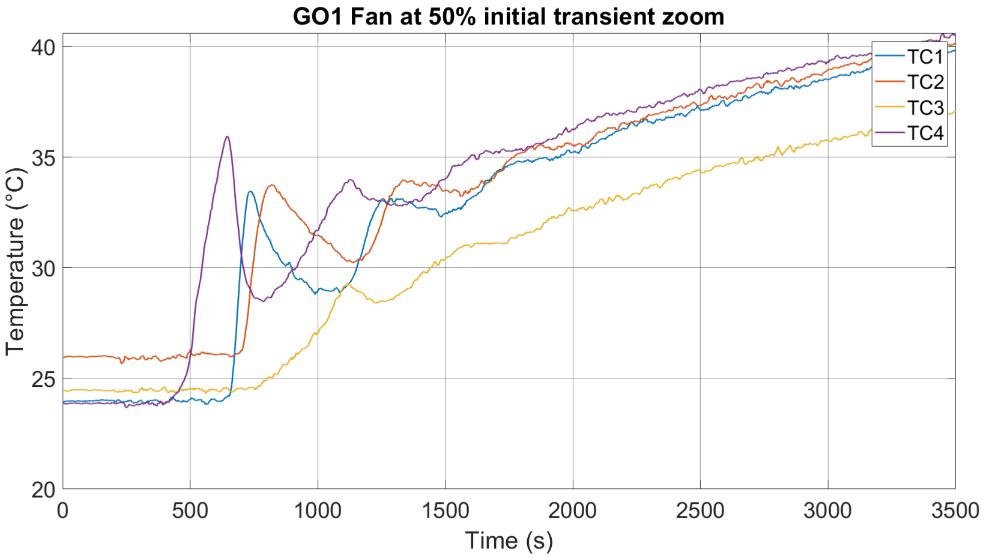
Experimental Results



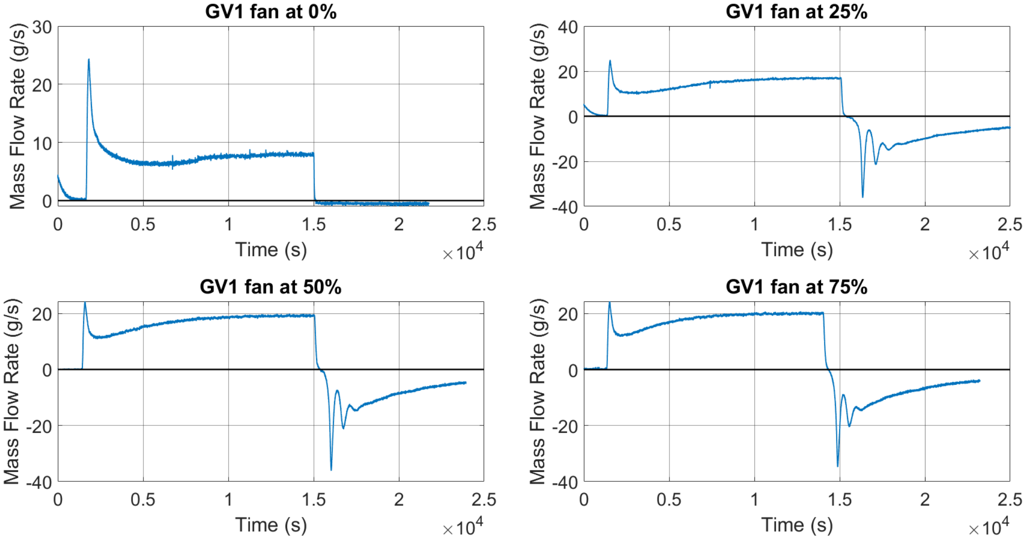
Experimental Results



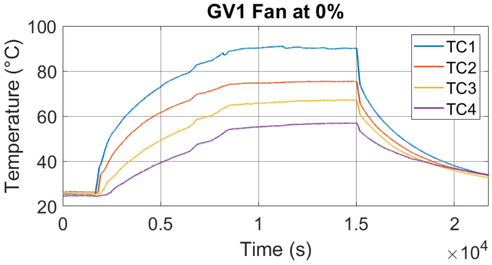
Experimental Results

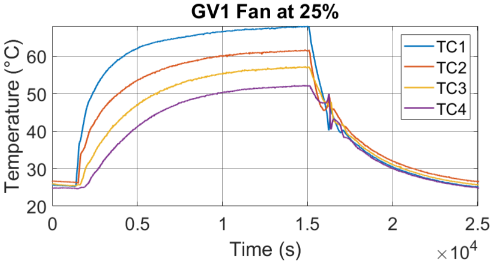


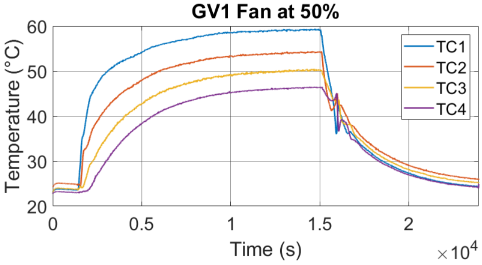
Experimental Results

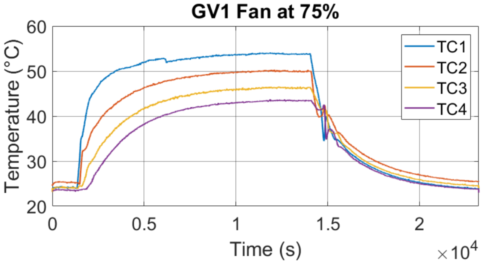


Experimental Results

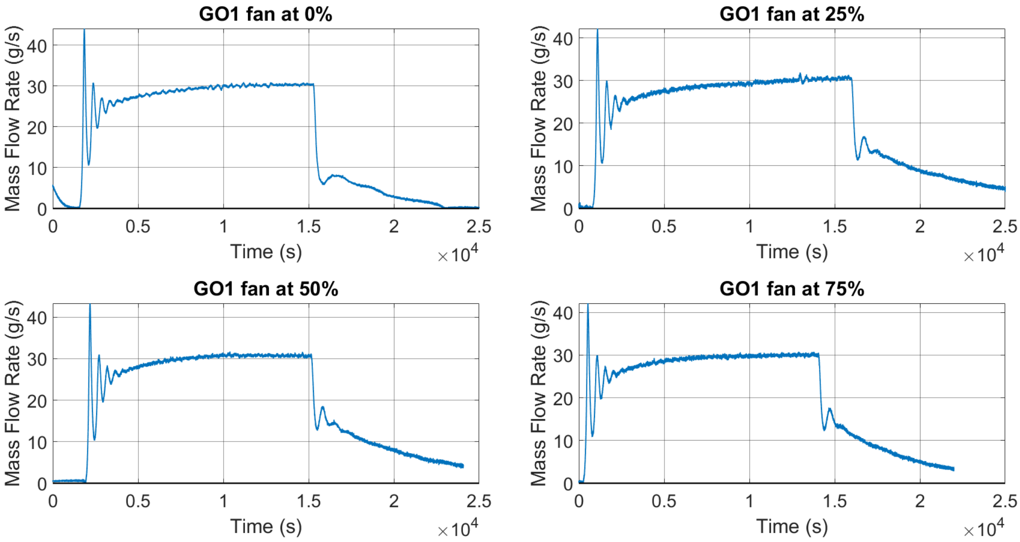




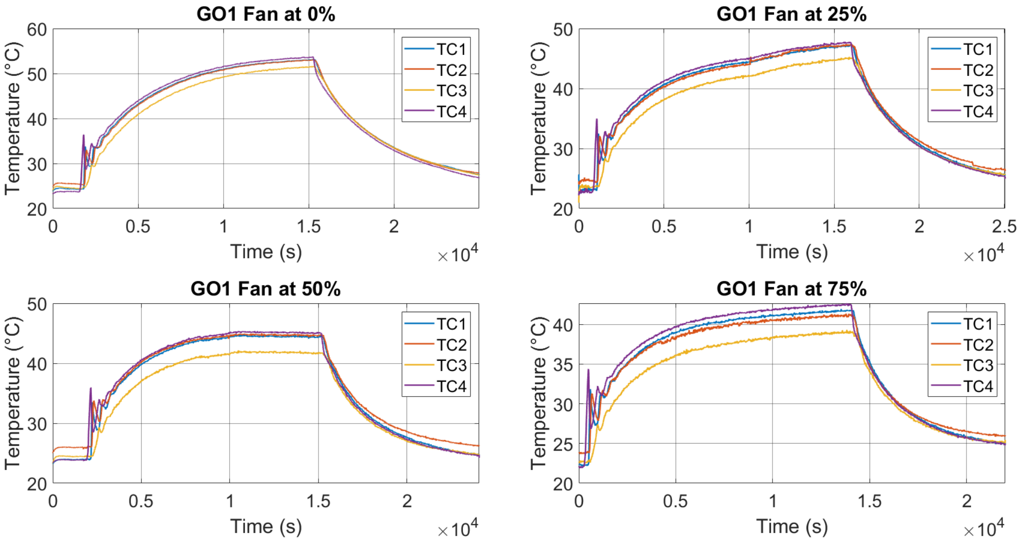




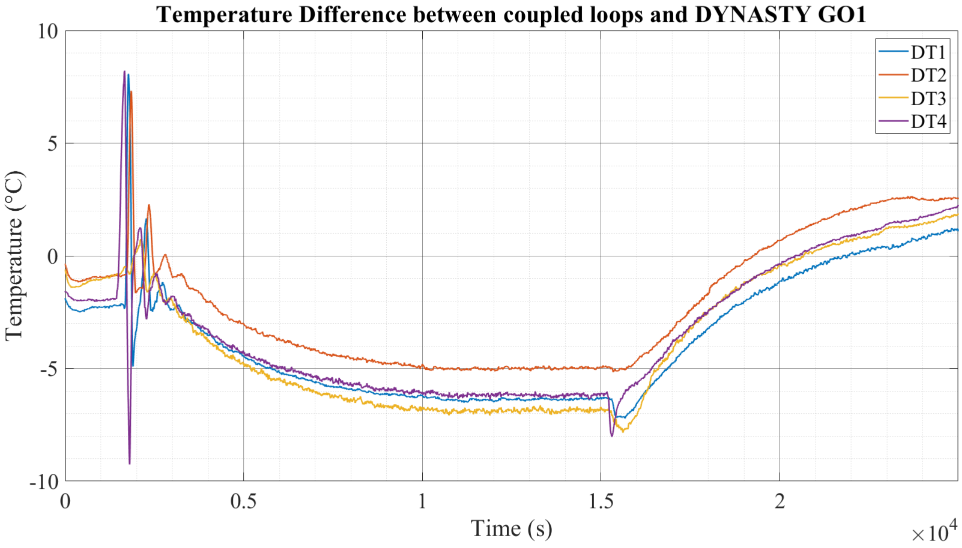
Experimental Results



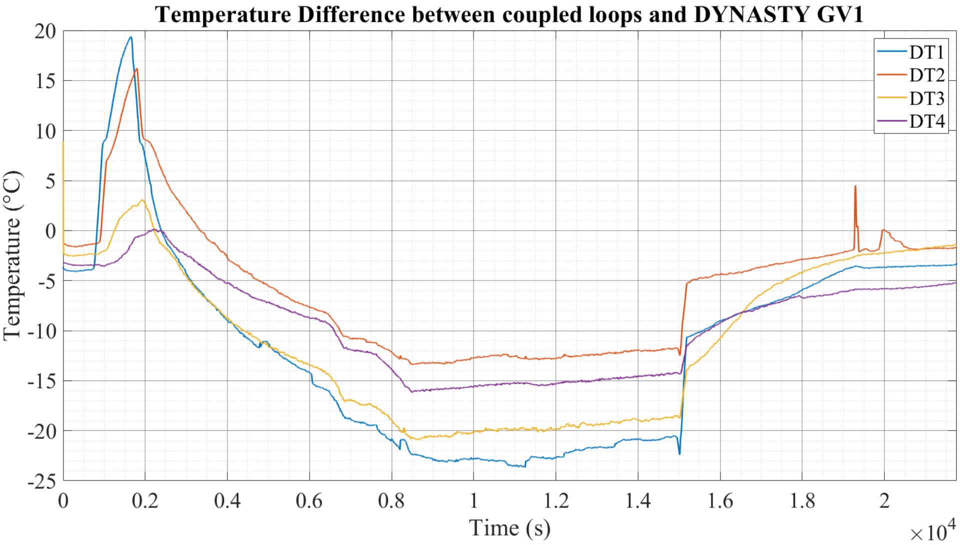
Experimental Results



eDynasty Experimental Campaign (HHHC)



eDynasty Experimental Campaign (VHHC)

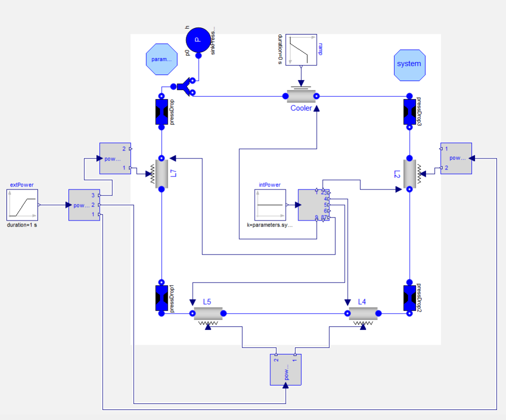


MODELICA Modelling

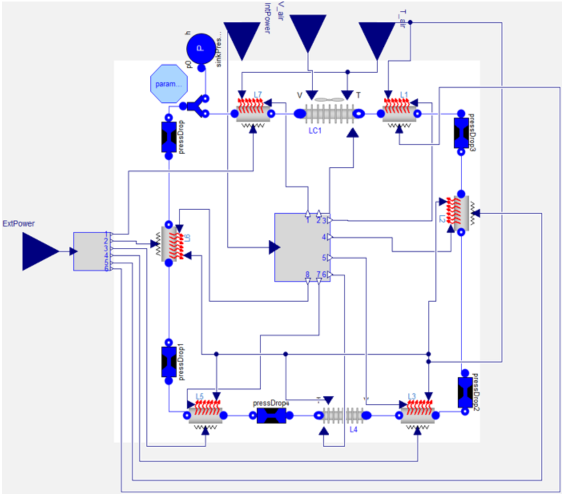
- Object-Oriented simulation language
- Acausal description using physical and engineering principles and balance equations
- Stand-alone components blocks linked by interfaces
- Differential Algebraic Equations, that must be translated into a Stiff ODE system
- Non-negligible dependency on the chosen integration algorithm.

DYNASTY Model

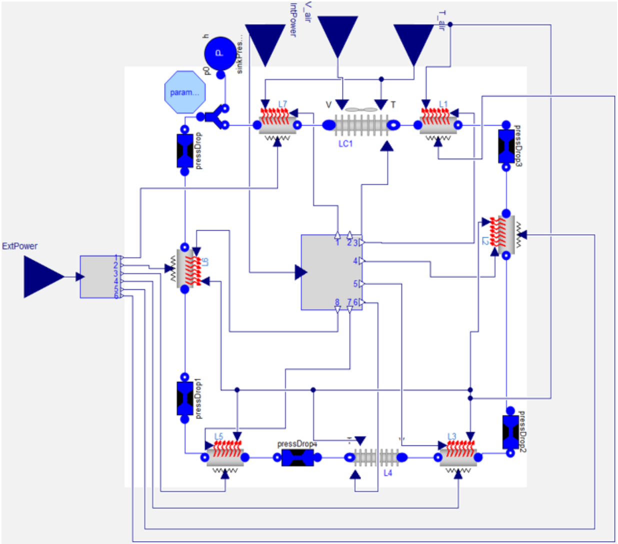
First Model



Upgraded Model



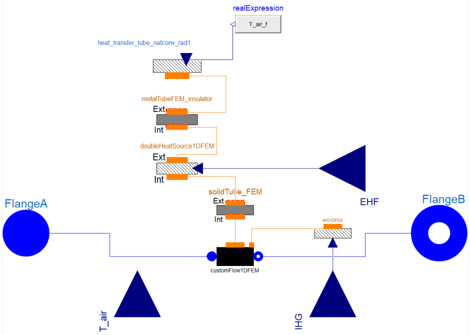
DYNASTY Model

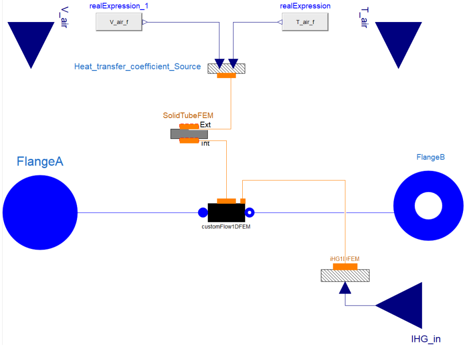


Model upgrades

- **Heat losses** between the facility and the environment
- **Finned** cooler model also accounting for natural circulation with air
- Churchill-Bernstein correlation for h
- **Pressure losses** for the MFM
- **Heat losses** for the mass flow meter (non-insulated pipe)
- Loading tank simulated imposing the pressure of the loop equal to the ambient one

Components Details



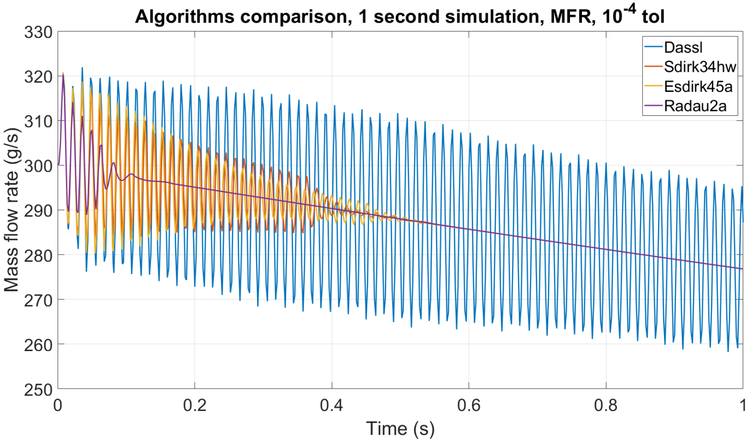


Numerical Integration Algorithms

Algorithm	Method	Stiff	Implicit	Order	Complete
DASSL	Linear multi-step (BDF)	Yes	Yes	1-5	Yes
Radau2a	Single-step (RK)	Yes	Yes	5	Yes
SDIRK34hw	Single-step (RK)	Yes	Yes	4	Yes
ESDIRK45a	Single-step (RK)	Yes	Yes	5	Yes
LSODAR	Linear multi-step (mixed)	Yes	Both	1-5	No

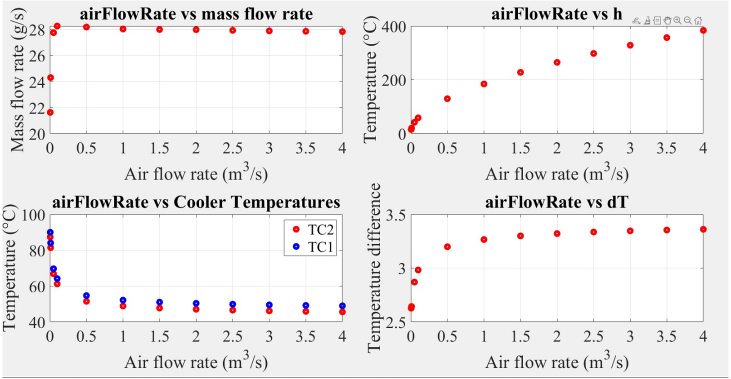
Table: Performance parameter: CPU-time ; test variable: mass flow rate

Numerical Integration Algorithms



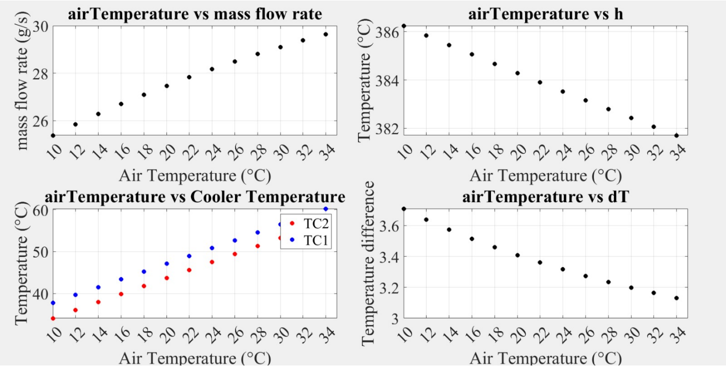
- **Chattering** during simulations (triggering of logic conditions which leads to generation of events and increased CPU time)
- **Radau2a** outperforms all other methods, dampening the oscillations in the initial steps

Model Parameters Sensitivity



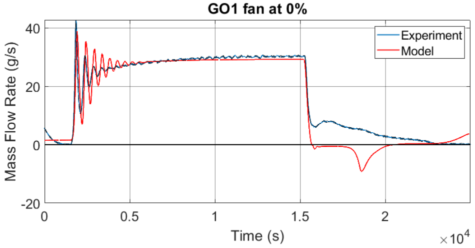
- Sensitivity analysis of the model changing **fan speed** (user-controlled input, constraint for the heat exchange with the environment).
- Understand where the effect of the fan is most visible, characterise the heat transfer in the cooler
- Conditions: air temperature 22 °C, power 450 W (5/8 GV1, 3/8 GV2)

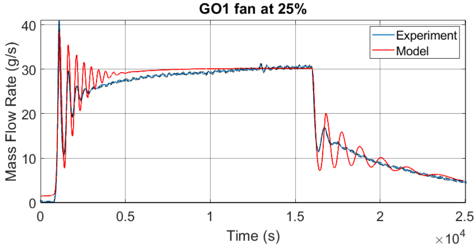
Model Parameters Sensitivity

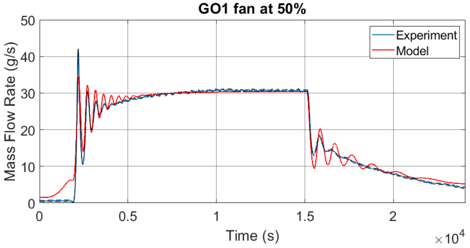


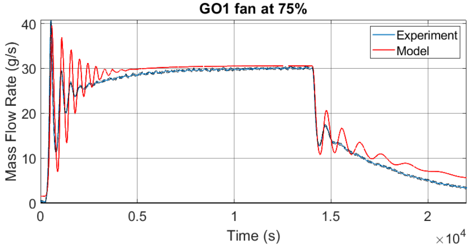
- Sensitivity analysis of the model changing **cooler air temperature** (ambient condition, linked to the heat dissipated by the cooler).
- Conditions: air flow rate 4 m^3s^{-1}, power 450 W (5/8 GV1, 3/8 GV2)

Validation: HHHC GO1 Case

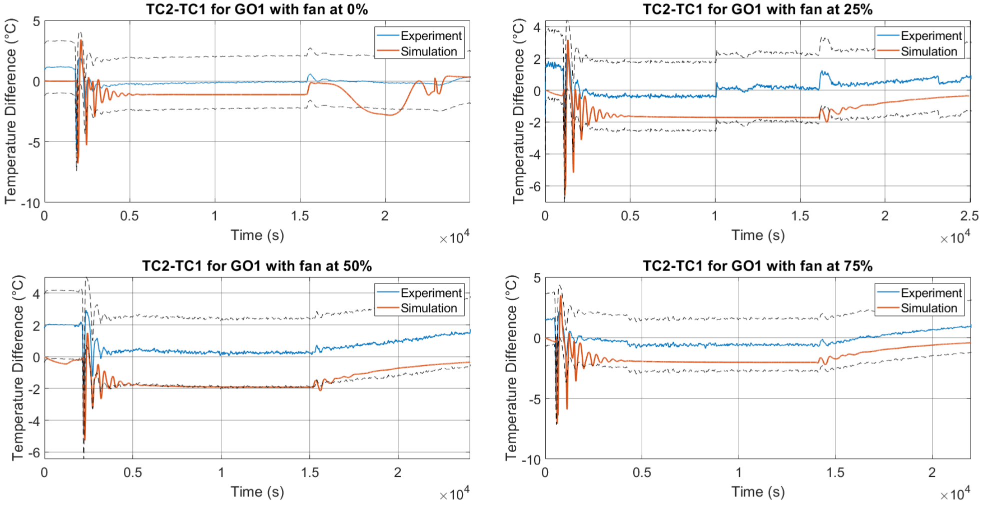




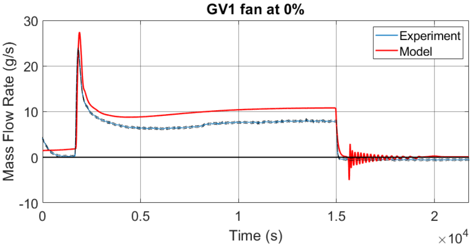


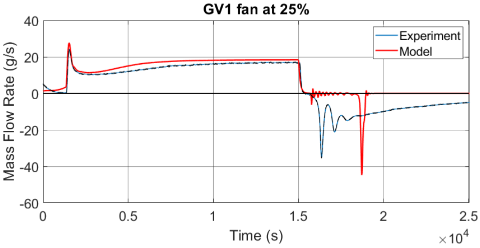


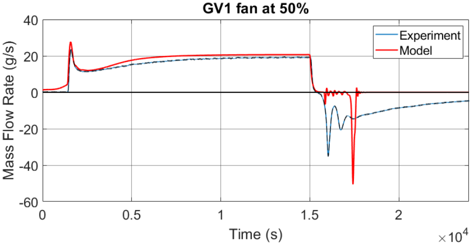
Validation: HHHC GO1 Case

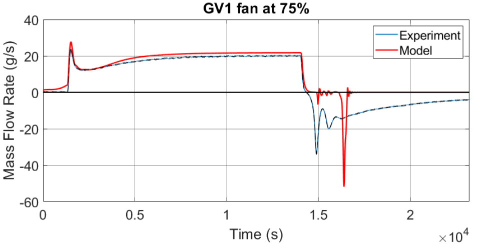


Validation: VHHC GV1 Case

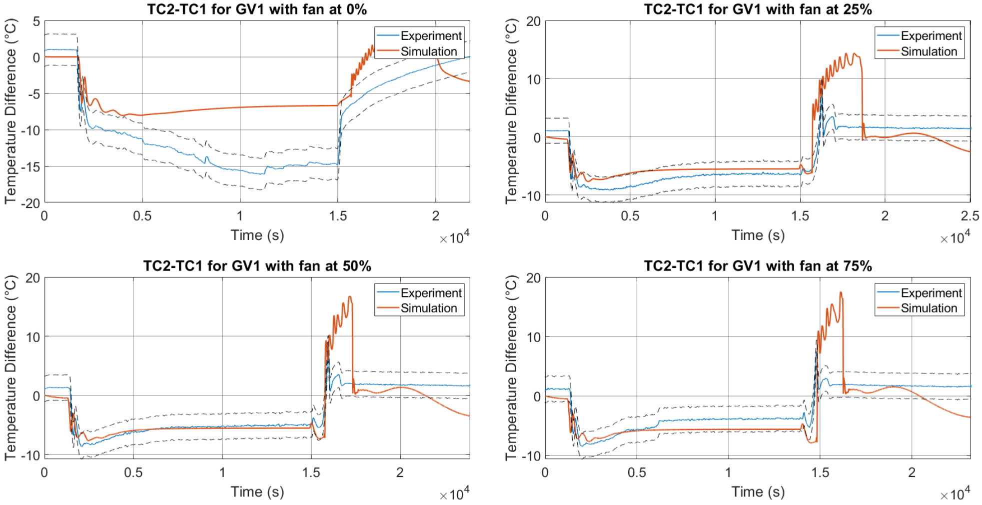








Validation: VHHC GV1 Case



Validation Summary

Fan speed	GO1 Cool	GO1 Heat	GV1 Cool	GV1 Heat	GV2 Cool	GV2 Heat
0&	Within	Within	Within	3.77 °C	2.56 °C	Within
25&	0.48 °C	Within	6.11 °C	Within	5.54 °C	0.34 °C
50&	0.16 °C	0.05 °C	5.94 °C	Within	5.65 °C	Within
75&	Within	Within	6.06 °C	Within	6.35 °C	Within

Table: Temperature results (error bounds $\pm$ 2.15 °C), square root mean distance between TC_2 and TC_1

Fan speed	GO1 Cool	GO1 Heat	GV1 Cool	GV1 Heat	GV2 Cool	GV2 Heat
0&	129.29%	2.64%	192.31%	10.23%	115.93%	5.63%
25&	16.1%	2.79%	108.24%	7.91%	99.36%	5.86%
50&	14.81%	1.28%	101.27%	6.74%	100.45%	5.64%
75&	39.38%	2.53%	120.67%	5.91%	99.39%	5.39%

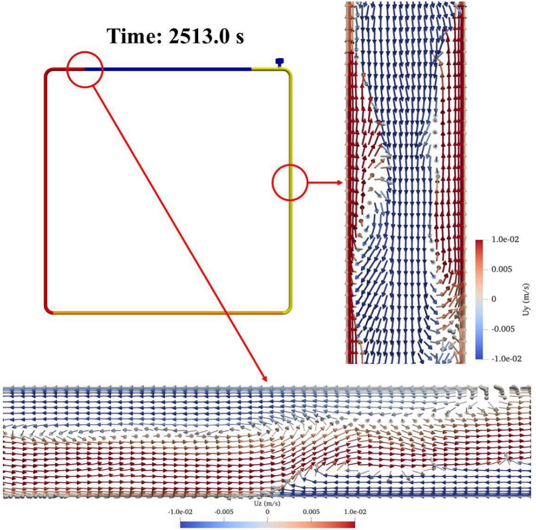
Table: Mass flow rate results (error bounds $\pm$ 0.2138 g/s), mean relative error

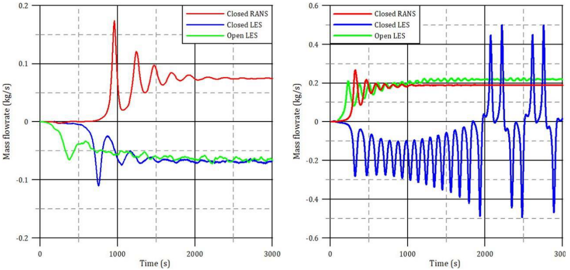
Validation Summary

Possible causes of discrepancy:

- Turbulence phenomena
- Recirculation in the tank region
- Possible boiling near the inner pipe walls
- Non-perfect agreement between initial conditions
- **Note:** the DYMOLA model cannot simulate two-phase flows

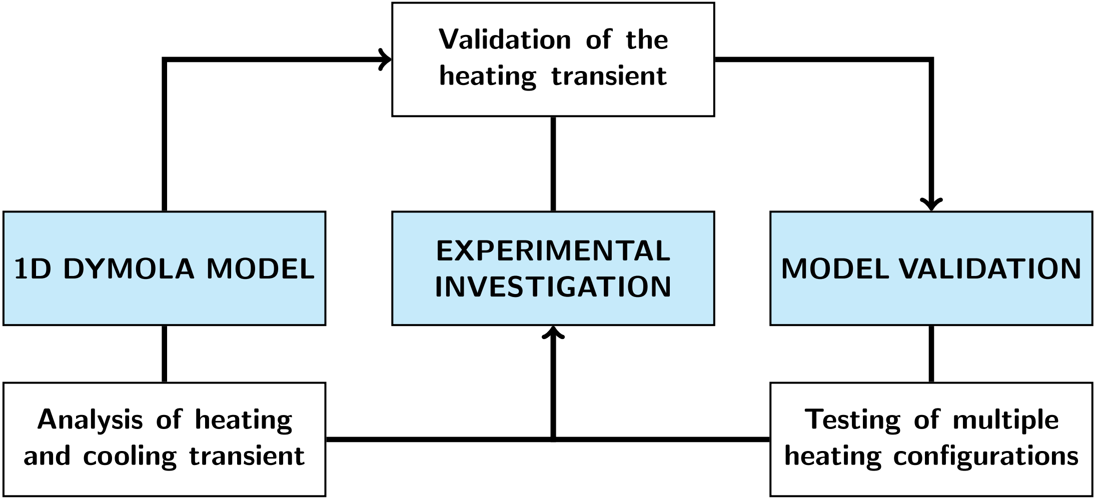
LES Modelling





Comparison of mass flow-rate between previous RANS results (POLIMI) and the result of the LES simulations (uniform heating at 1kW and cooler temperature at 180°C, left ; uniform heating at 5.3kW and cooler temperature at 240°C)

Conclusions



Future Works

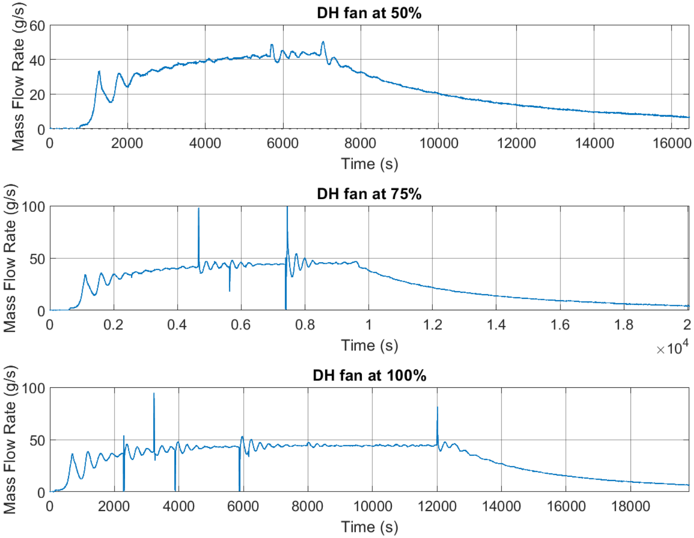
- Installation of the insulant layer
- New validation campaign with both water and glycol
- Inclusion of the feed and discharge tanks in the model
- Realisation of different power transients
- 3D analysis of the cooling transient
- Coupled model with eDYNASTY facility

THANK YOU FOR THE ATTENTION!

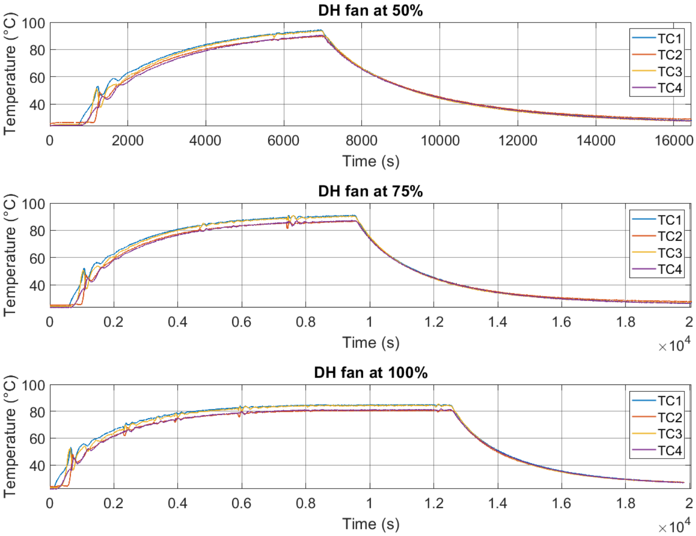
DYNASTY Characteristics

DYNASTY CHARACTERISTICS	
Size	Height: 3.09 m Width: 3.10 m Piping: φ 42.16 mm ; thickness 2 mm
Thermal carrier	Water TYFOCOR LS (propylene glycol)
Material	AISI 304/316 L
Heating system	Fibreglass knitted and braided electrical strips (up to 5.3 kW)
Heat exchanger	Finned tube coupled with a cooling fan
Temperature range	20 / 95°C (water)
Pressure	1 atm (filling tank top)

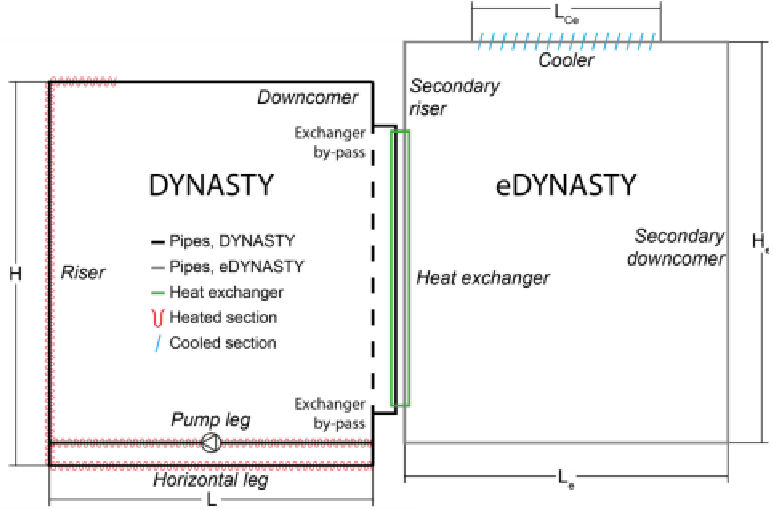
DH Case


DH fan at 50%
Mass Flow Rate (g/s)
0
20
40
60
0
2000
4000
6000
8000
10000
12000
14000
16000
Time (s)
DH fan at 75%
Mass Flow Rate (g/s)
0
50
100
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (s)
×10^4
DH fan at 100%
Mass Flow Rate (g/s)
0
50
100
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Time (s)

DH Case


DH fan at 50%
Temperature (°C)
100
80
60
40
0
2000
4000
6000
8000
10000
12000
14000
16000
Time (s)
TC1
TC2
TC3
TC4
DH fan at 75%
Temperature (°C)
100
80
60
40
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (s)
×10^4
TC1
TC2
TC3
TC4
DH fan at 100%
Temperature (°C)
100
80
60
40
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (s)
×10^4
TC1
TC2
TC3
TC4

Coupled System



Coupled System

- **DYNASTY-eDYNASTY coupling**
  - Pipe-in-pipe heat exchanger
  - Internal pipe (DYNASTY) diameter is 38mm
  - Annulus pipe (eDYNASTY) diameter is 60mm